By integration from 0 to, say, T_2 (or from $-\infty$ to $\log T_2$) at constant pressure p_2, we obtain

$$T_2 \log p_2 = \int_{-\infty}^{\log T_2} (T \log p)\ d\ (\log T); \tag{11}$$

on figure 2 the integral would be represented by the total area (between the T_2 line and $-\infty$ *to the left*) that would extend from the p_2 line *upward* to $-\infty$. Such areas will hereinafter be denoted by symbols of the type $(-\infty_x)$ (p_2) $(-\infty_y)$. Although this area is of infinite extent, it does possess a direct utility that becomes evident in the following paragraph.

3. *For any joint variation of temperature and pressure,* as with altitude, we have from equation (7),

$$g\ (z_2-z_1)=R\left[\int_{(2)}^{(1)} d\ (T \log p) - \int_{(2)}^{(1)} (T \log p)\ d\ (\log T)\right] \tag{7}$$

$$=R[(T \log p)_1-(T \log p)_2 - \int_{(2)}^{(1)} (T \log p)\ d\ (\log T)] \tag{12}$$

On figure 2 the three terms on the right of equation (12) would be represented graphically by the area

$$(-\infty_x)\ (p_1)\ (-\infty_y)-(-\infty_x)\ (p_2)\ (-\infty_y) - (-\infty_y)\ (p_1)\ (p_2)\ (-\infty_y) = (-\infty_x)\ (p_1)\ (p_2)\ (-\infty_x).$$

Thus,

$$g\ (z_2-z_1)=R \cdot \text{area}\ [(-\infty_x)\ (p_1)\ (p_2)\ (-\infty_x). \tag{12a}$$

Now, if on figure 2 a temperature line mn is drawn similar to the one used in the adiabatic chart, figure 1, so that area *2nb* equals area *bim*, we have

$$g\ (z_2-z_1)=R \cdot \text{area}\ [(-\infty_x)\ (n)\ (m)\ (-\infty_x)] = R \cdot \text{area}\ [(-\infty_x)\ (m)\ (-\infty_y) - (-\infty_x)\ (n)\ (-\infty_y)], \tag{13}$$

or, by the remarks following equation (11),

$$g\ (z_2-z_1)=R[(T \log p)_m-(T \log p)_n] = R\ T_{mn}\ (\log p_1-\log p_2). \tag{15}$$

The significance of equation (14) is that, if the temperature-pressure record of a sounding be depicted on the coordinates $\log T$ and $T \log p$, and if we delineate a "mean effective" temperature line mn in the way specified, then the difference of geopotential, and thus of altitude between points *1* and *2*, is equal to R times the linear separation of points m and n; this conclusion is valid so long as the construction of the pressure lines conforms to the requirements indicated above, which are fulfilled in the Refsdal chart. As previously mentioned, that chart provides a scale on the right margin to which linear distance mn may be transferred and from which the difference of geopotential may be read directly.

The identity of equations (3) and (15) will be evident, as well as the essential identity of the constructions for determining the required mean effective temperature on the two charts. The only essential difference between the two procedures for the determination of geopotential and altitude in a static atmosphere is that with the adiabatic chart, R, T_e and $\log (p_o/p_1)$ must actually be multiplied, whereas by a rather circuitous but very ingenious line of reasoning Refsdal has evolved a chart and scale that provide the product directly.

The Refsdal chart also provides the usual dry and wet adiabatics, the mixing ratio at saturation, etc. As on the tephigram, areas on the Refsdal chart have the dimension and significance of energy; but, unlike the tephigram, distances along the ordinates have also the above significance of geopotential energy.[5]

The writer ventures to suggest that meteorology is much in need of a diagram that will represent other energy data for the atmosphere, in addition to geopotential, as linear distances rather than as areas. Areas are too troublesome of accurate evaluation and frequently too difficult of proper interpretation. It is exactly for this reason that the engineer has abandoned the temperature-entropy diagram in practical work, and has found the Mollier (enthalpy-entropy) chart to be so much more useful.

[5] Cf. footnote 2. p. 69.

VARIABILITY ISOCRYMAL MAPS FOR THE GREAT PLAINS

By EARL E. LACKEY

[University of Nebraska, Lincoln, Nebr., March 1936]

The series of variability isocrymal maps of the Great Plains described in this paper is a continuation of a corresponding study recently made by the author for Nebraska only.[1]

In constructing a series of frost maps, it was considered more desirable to use median and percentile dates than dates calculated from means and standard deviations. Not only is it easier to calculate percentile dates from the median, but also such dates register exactly what has occurred according to the record, whereas dates calculated from the means and standard deviations, although they may present a symmetrical picture, do not indicate what actually has occurred.

Means have not been computed for all the 500 stations in the 10 States represented by this study; but means and corresponding percentile deviations have been computed for Nebraska.[2] It was found that both the mean date and median date of the first killing frost of autumn at Beatrice, Nebr., according to a 43-year record, was October 10. The mean dates and median dates for the 71 Nebraska stations were in agreement only 30 percent of the time. In normal distributions medians and means are always in agreement.

The mean date of the first killing frost of autumn at Madison, Nebr., according to a 37-year record, was October 5—3 days *earlier* in the year than the median date, October 8. Expressed in another way, the first killing frost of autumn at Madison occurred earlier than the mean date 15 times, and later 20 times. At 25 percent of the 71 Nebraska stations, the mean date of the first killing frost of autumn was *earlier* than the median date.

The mean date of the first killing frost of autumn at Broken Bow, Nebr., according to a 39-year record, was October 2—7 days *later* in the year than the median date, September 25. In fact, the first killing frost of autumn occurred 23 times before, and 16 times after, the mean date. Of course the first killing frost of autumn occurred

[1] The Geographical Review, Vol. XXVI, No. 1, January 1936.

[2] Climatic Summary of the United States (U. S. Weather Bureau Bulletin W), Sections 38 and 39. Washington 1930.

just 19 times before and 19 times after September 5, the median date. At 46 percent of the 71 Nebraska stations, the mean date of the first killing frost of autumn was *later* than the median date. In other words, if the farmers of Nebraska think of the mean in a normal distribution when making their calculations concerning the first killing frost of autumn, most of them miss by far what actually has happened; for, according to the record, killing frost has occurred at the 71 Nebraska stations nearly twice as often before the mean as after it (ratio 46:24).

At Ashland, Nebr., with a 41-year record, the last killing frost of spring according to both the mean and the median is April 27. The mean and median dates agree at 25 percent of the 71 Nebraska stations.

The mean date of the last killing frost of spring at Lexington, Nebr., according to a 39-year record, is May 13—7 days later than the median, which is May 6. Killing frost at Lexington actually occurred earlier 24 times, and later 15 times, than the mean date. At 50 percent of the 71 Nebraska stations, the mean date of the last killing frost of spring has been later than the median.

The mean date of the last killing frost of spring at Atkinson, Nebr., is May 10—3 days earlier than the median date, which is May 13. Killing frost at Atkinson actually has occurred earlier 16 times, and later 18 times, than the mean date. This has been the case at 25 percent of the 71 Nebraska stations.

The study of frost frequency indicates therefore that the last killing frost of spring has occurred at Nebraska stations later than the mean date twice as often as earlier.

Thus it is seen that the frost hazard in spring for Nebraska as a whole is not as great as the mean might lead one to believe, especially if one is thinking of the mean in a normal distribution.

It stands to reason, therefore, that the farmer will find the median a safer guide than the mean, because it indicates just what the frost hazard has been. To the extent that one considers the past record as a safe criterion, the median and percentile deviations may be used as a guide in the planting of crops and other agricultural operations affected by killing frost.

Although corresponding computations for the other States of the Great Plains have not been made, it is assumed that the Nebraska case is typical in respect to the relation between means and medians. It is desirable that other samples in the area be worked out in order to check this assumption, however.

FINDING MEDIAN AND PERCENTILE DATES

At Independence, Kans, the median date for the first killing frost of autumn, i. e., the date on or before which the first killing frost occurs 50 percent of the time, is October 23. This date is based on what has actually occurred during the past 57 years, and was worked out in the following manner. On a special calendar for September, October, and November the dates of the first killing frosts of autumn were checked for each of the 37 years from 1877 to 1934, respectively. Counting forward from the earliest date, September 26, the 50-percentile or 29th date falls on October 23. From this as a median, one may count forward or backward to find any desired percentile date. For purposes of this study the 20-, 50-, and 80-percentile dates were computed. These dates are shown to be October 10, October 23, and November 1, respectively; they signify that the first killing frost of autumn occurred at Independence on October 10, *or earlier*, 20 percent of the time, on October 23, *or earlier*, 50 percent of the time, and November 1, *or earlier*, 80 percent of the time. A similar sheet [3] was prepared for each of the 500 stations on the Great Plains. Only 40 stations with a record of fewer than 20 years were included in the study; the longest record was that of Manhattan, Kans., 71 years.

On a special calendar for March, April, and May the 20-, 50-, and 80-percentile dates were computed for the last killing frost of spring for Independence. These dates are shown to be April 27, April 13, and April 1, respectively. This signifies that a killing frost occurred at Independence on April 27, *or later*, 20 percent of the time, on April 13, *or later*, 50 percent of the time, and on April 1, *or later*, 80 percent of the time. A similar sheet was prepared for each of the 500 stations on the Great Plains.

ISOCRYMAL MAPS FOR AUTUMN

With these computations for the 500 stations, the 50-percentile or median dates for the first killing frosts of autumn were entered on an outline map of the Great Plains and isocrymes drawn with an interval of 5 days (fig. 2). An isocryme on this map means that the last killing frost of autumn occurred on the designated date, *or earlier*, 50 percent of the time. Each of the other maps for autumn is to be similarly interpreted.

The 20-percent and 80-percent isocrymal maps for autumn are more important, perhaps, than the 50-percent or median map (figs. 1 and 3). On these maps the isocrymes pass through those places where the first killing frost of autumn occurred on the designated dates, *or earlier*, 20 percent of the time, and 80 percent of the time, respectively. For example, in only 20 percent of the years at Topeka, Kans., has the first killing frost of autumn occurred by October 8, *or earlier*, whereas in 80 percent of the years it has occurred on October 27, *or earlier.*

As examples of the practical application of these data, we may mention first that a cattle feeder may desire a large late-maturing variety of corn for ensilage; the variability isocrymal maps for autumn inform him as to the percentage of frost hazard he is risking with such varieties. Again, in selecting seed corn from the standing stalk in autumn, if he accepts as a criterion what has happened in the past, the farmer can make an intelligent guess as to the approximate date on, or before, which such work should be completed.

ISOCRYMAL MAPS FOR SPRING

The method used in constructing the spring maps was similar to that employed in making the autumn maps. For Kearney, Nebr., it was found that the last killing frost of spring occurred on May 13, *or later*, 20 percent of the time; on April 30, *or later*, 50 percent of the time; and on April 25, *or later*, 80 percent of the time.

With corresponding data at hand for the 500 weather stations on the Great Plains, the 20-, 50-, and 80-percentile maps for spring were constructed (figs. 4, 5, and 6).

A farmer in the vicinity of Kearney, Nebr., knowing that early potatoes as a rule bring high prices, or mature before the hot season arrives, may use the spring isocrymal maps to advantage. If he thinks that planting potatoes early and taking a chance with frost is better than risking a low price, he may desire to plant so the potatoes will be up on April 25, with a 90-percent hazard, rather than to plant so they will just be coming up on

[3] Climatic Summary of the United States (U. S. Weather Bureau Bulletin W), Sections 8, 9, 10, 11, 13, 14, 23, 24, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, and 43.

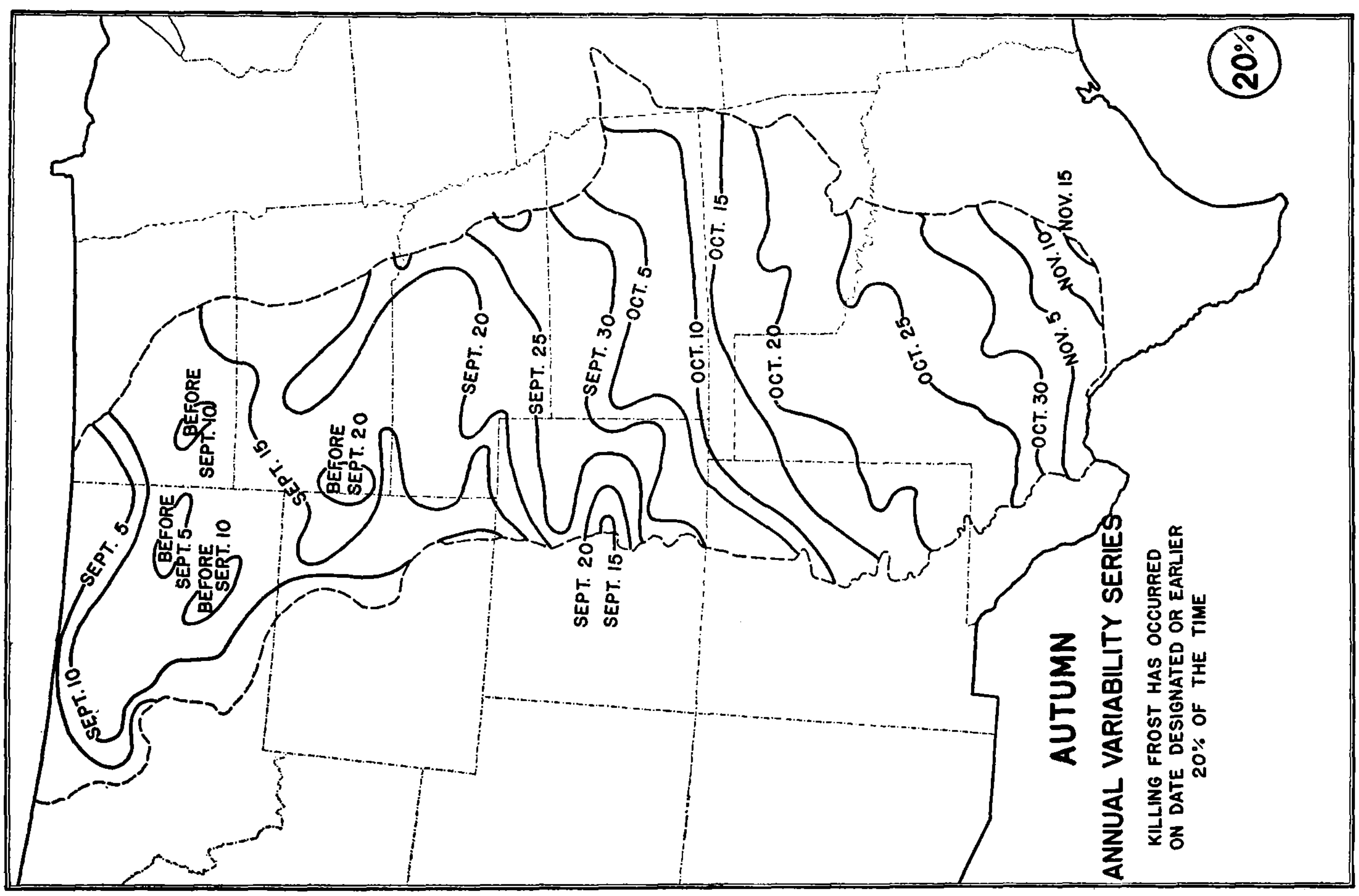

FIGURE 1.

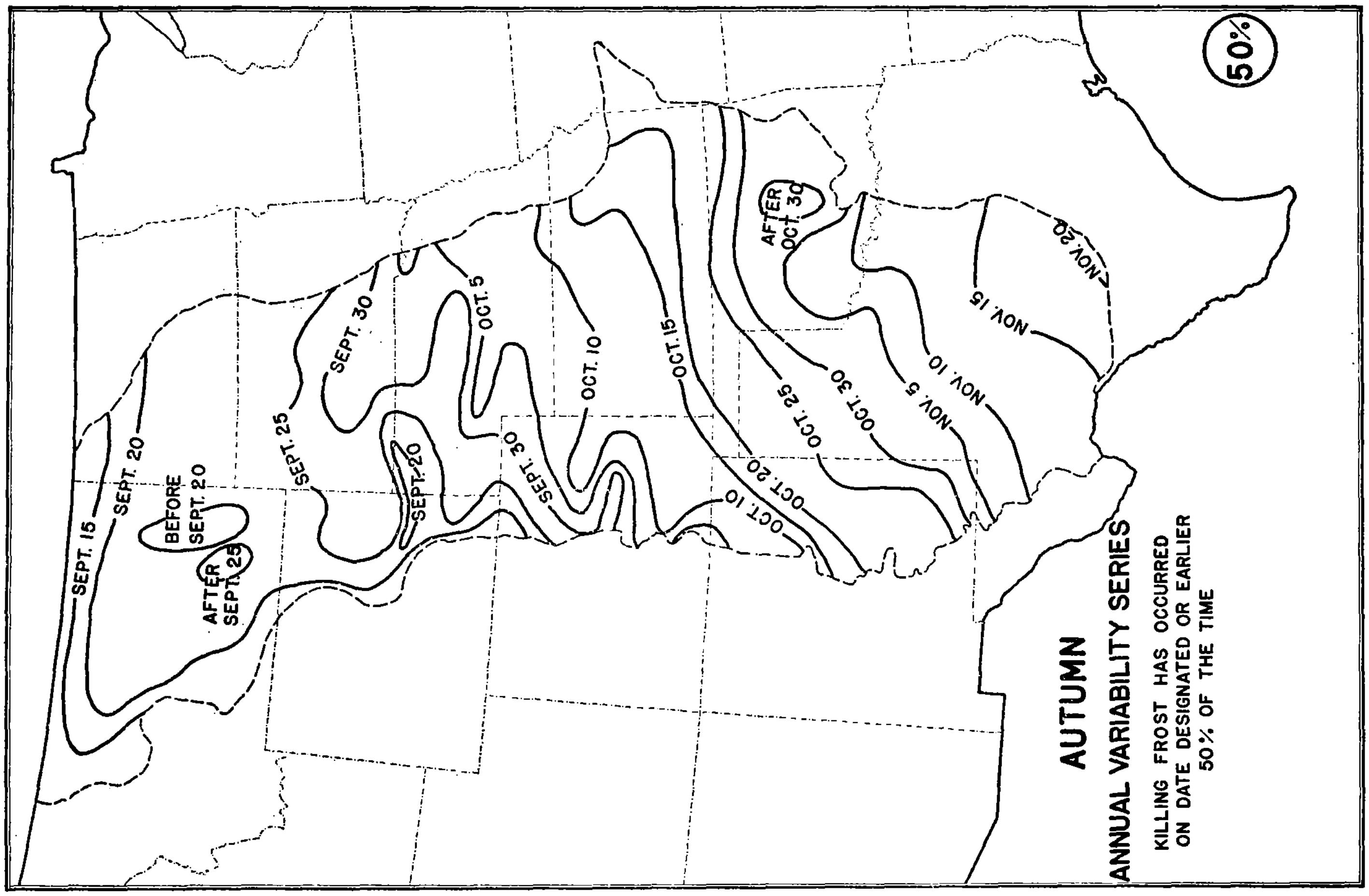

FIGURE 2.

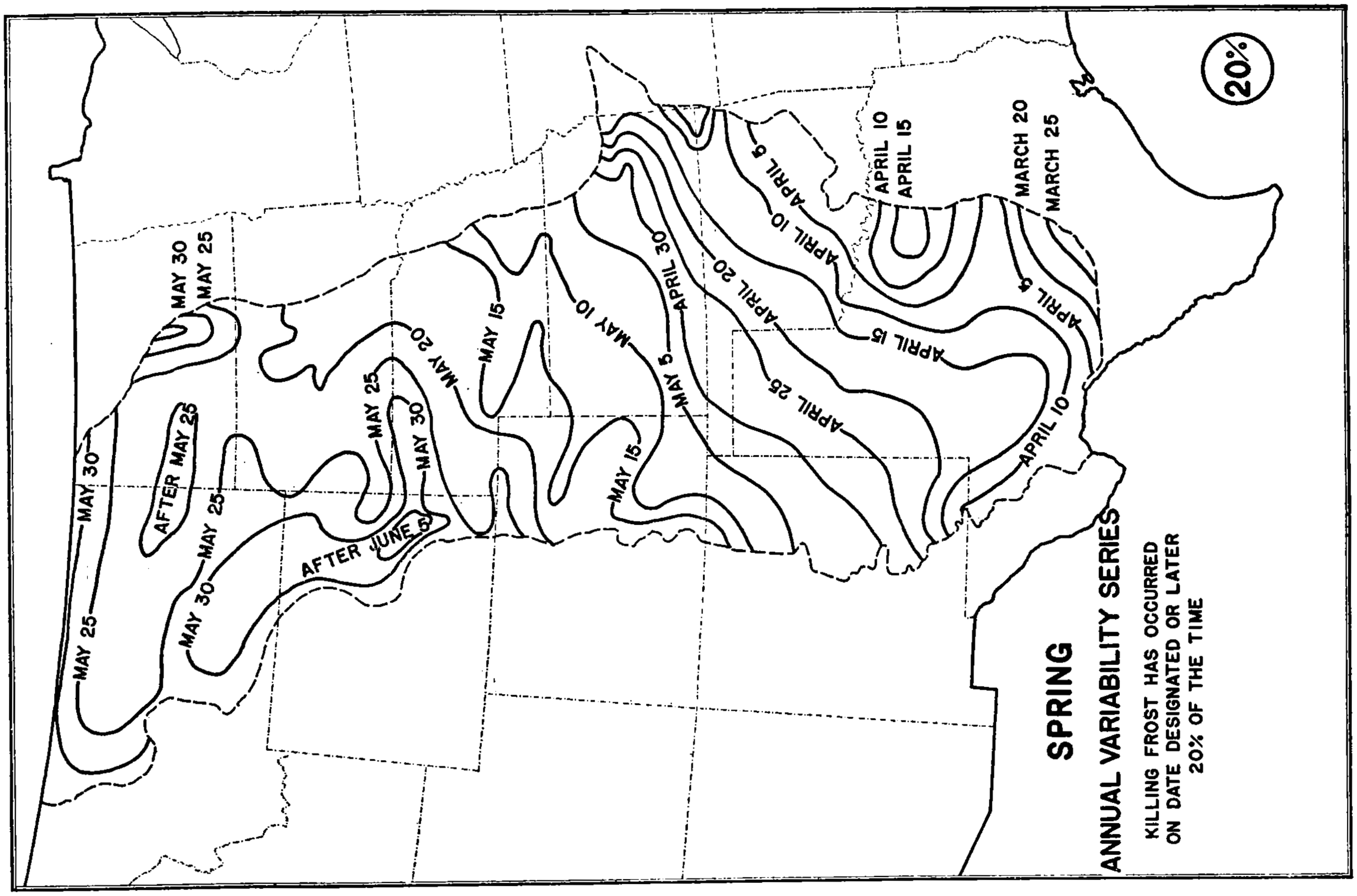

FIGURE 4.

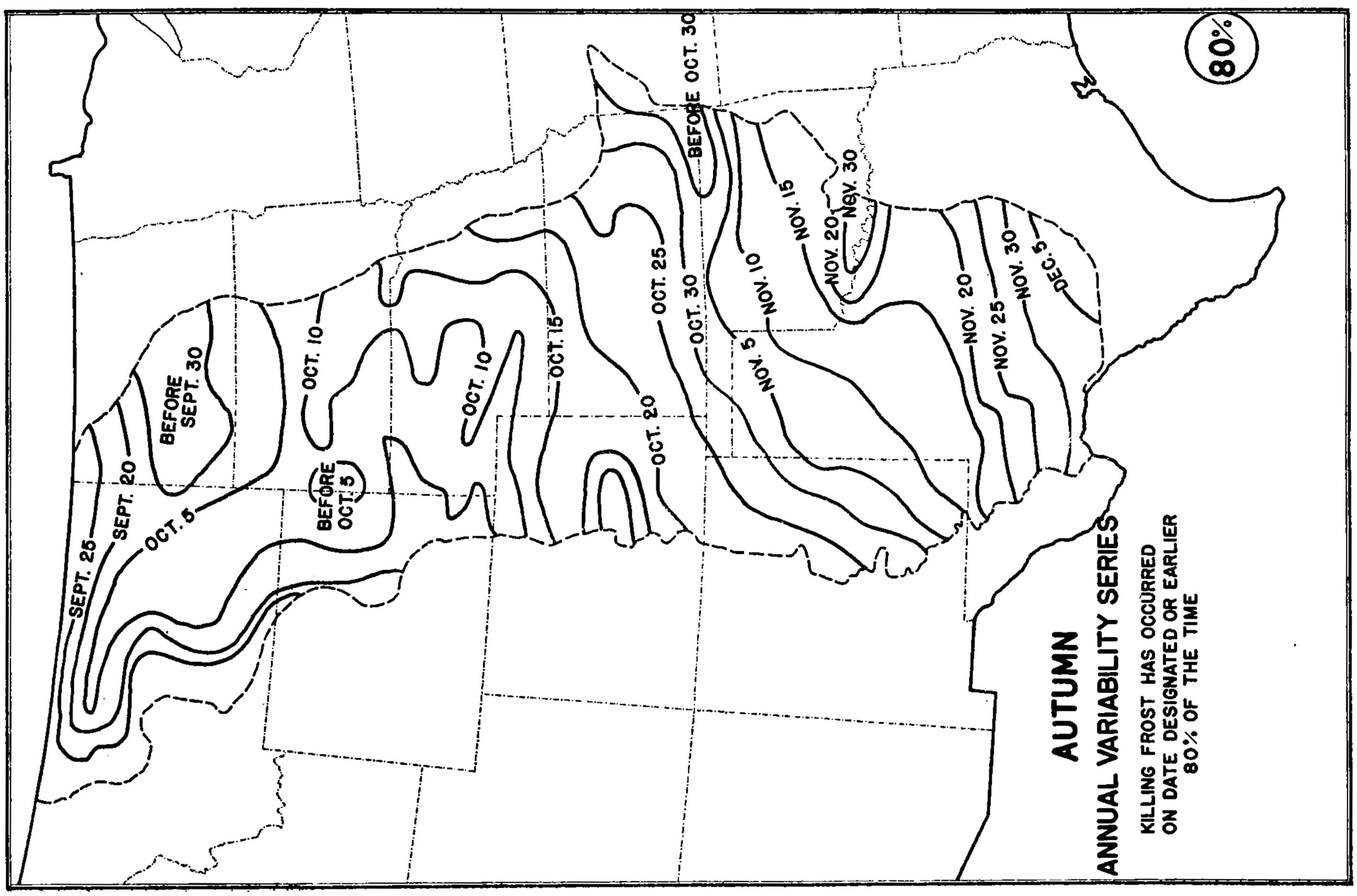

FIGURE 3.

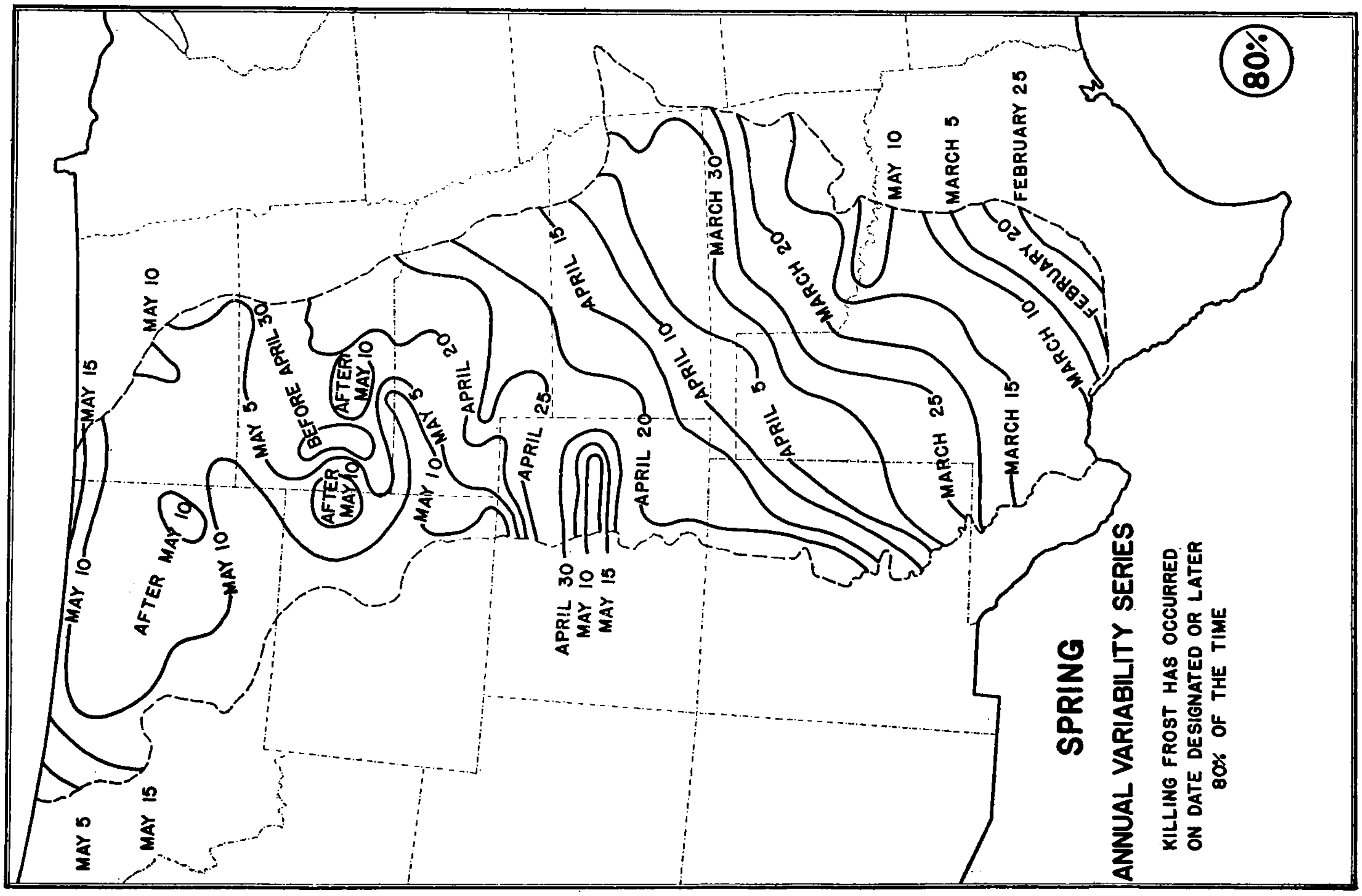

FIGURE 6.

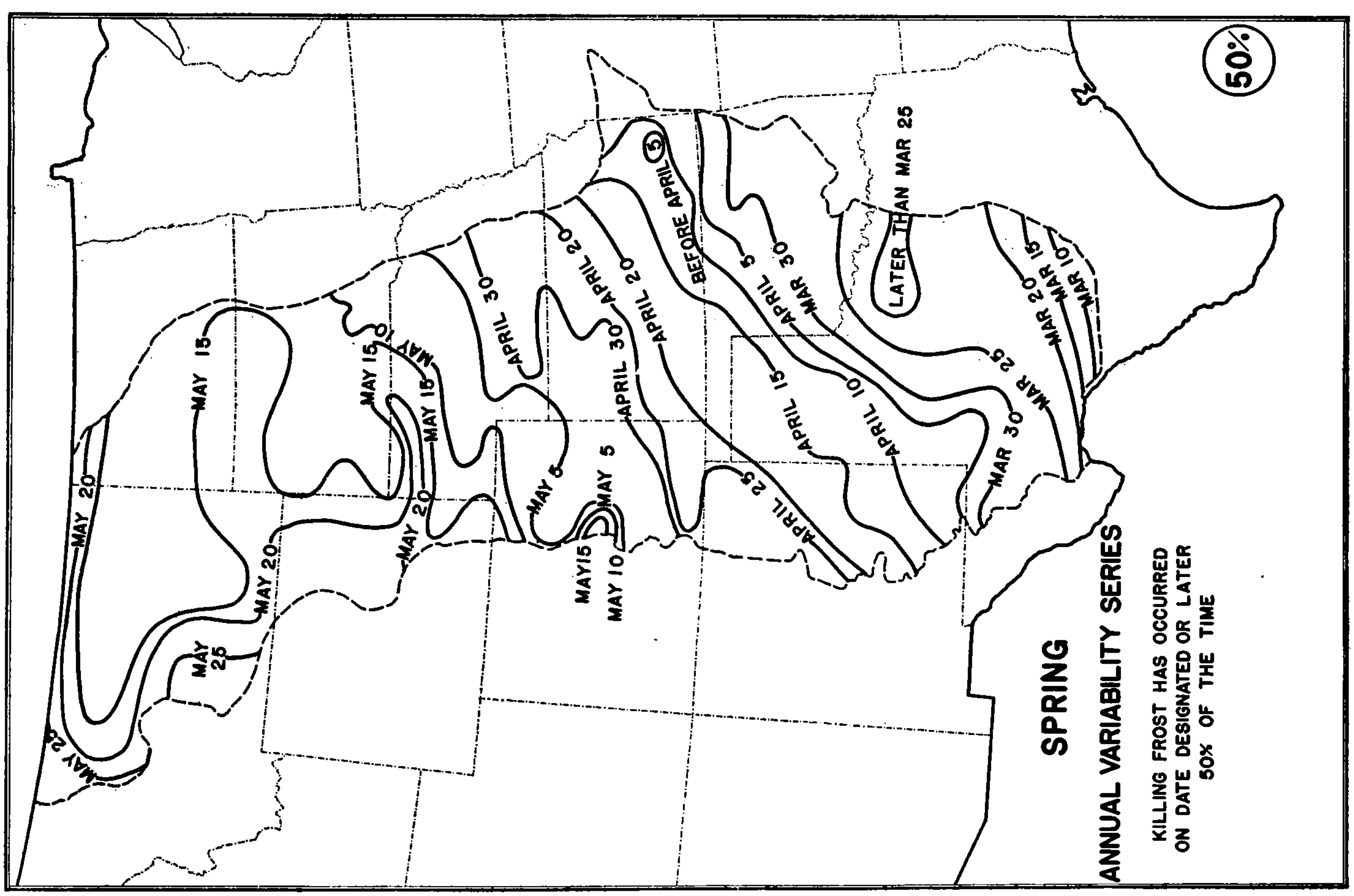

FIGURE 5.

May 13, with the hazard only 20 percent. By consulting the variability maps for spring he may know that he is taking an 80-percent chance (4 chances in 5) that his corn will be frosted if it is up on April 25; but he knows also that corn planted on April 25 usually is up by May 13, or earlier—none too late for a good crop prospect. Or he may wish to take an 80-percent chance on one-third or one-fourth of his crop, knowing that unseasonably dry or cool weather or rains may interfere with the later planting. Thus by intelligently taking the frost hazards into consideration he may succeed in his farming operations a larger percentage of the time.

ISOCRYMAL MAPS OF GROWING SEASON

The data given by the records of the United States Weather Bureau for Manhattan, Kans., were used for the construction of the 20-, 50-, and 80-percentile maps showing the periods free from killing frosts. The percentile dates were calculated by arranging the lengths of periods for the 43 years in a numerical sequence. From this sequence it was found that Manhattan has a frost-free period of 188 days, *or more*, 20 percent of the time, 174 days, *or more*, 50 percent of the time, and 154 days, *or more*, 80 percent of the time. The data for each of the 500 stations on the Great Plains were treated in a similar manner for the construction of the three isocrymal maps that show the length of the growing season (figs. 7, 8, and 9).

The dairyman who depends on forage crops for pasturage for his cows wants to know what percentage of the year will be free from killing frosts. If he is a careful planner he may consult the maps of length of growing season for the percentage of hazard involved. He may be satisfied with an 80-percent hazard or he may not want to risk more than 20 percent.

LIMITATIONS OF THIS STUDY

The reliability of a series of maps of this kind is limited by many factors, among which the following may be noted:

1. *The short period of time during which records have been kept.*—The average length of record is about 35 years, varying from 20 to 71. The longer record, of course, is more desirable. As a rule, stations with fewer than 20 years were not used.
2. *Errors in observation* are likely to occur, especially in the spring when the response of vegetation to freezing usually is not so noticeable nor so crucial as in autumn.
3. *The relative weight to be given to short-time and long-time records* is hazardous; here interpolation and adjustment of the records were not attempted.
4. *When the recorded number of years was even, the earliest year was discarded*, in order to have the median fall in the middle of a day rather than at midnight or between two days. By so doing, any fractional part of a day was more easily disposed of when the percentile dates were being calculated.

CONCLUSIONS

The uniqueness of this variability series of maps lies not only in its portrayal of the *median dates* relative to frosts and length of growing season in all parts of the Great Plains, but also in the portrayal of the 20- and 80-percentile dates. It is not contended that they could be used to specifically forecast frost occurrences from year to year in different parts of the Plains; but there is given a summary of what the conditions in the past have been, and, to the extent that the records of the past may be used as a criterion for the future, the maps may be utilized as an indication of the general run of frost conditions that may be expected in future years in the Plains country.

The maps show that in spring there is a spread of about 30 days, in the southern part of the Great Plains, between the dates on the 20- and 80-percent maps; whereas in the northern part of the region, there is a spread of about 15 days. This indicates that while the opening of spring occurs later in the north, it advances more rapidly than in the southern part.

In the autumn, in the southern part of the Great Plains, the spread is about 20 days between the 20- and 80-percent maps, and about the same in the northern part of the region. This indicates that the season advances in autumn about as fast in the northern part of the region as in the southern.

Assuming that climatic factors are relatively constant, a farmer can, by scanning these maps, make an intelligent guess as to what he may expect in different percentages of the time with reference to the last killing frost of spring, the first killing frost of autumn, and the length of growing season.

It is the writer's opinion that percentile dates calculated from the median furnish a better criterion for practical purposes than corresponding percentile dates calculated from the mean.

INTERCORRELATIONS BETWEEN CLIMATIC VARIABLES IN THE CORN BELT [1]

By JOHN KERR ROSE

[University of Chicago, March 1936]

It is a popular belief that rain tends to reduce temperature, and that one hot day is likely to be followed by another. This study is an attempt to discover how well such assumptions apply to the succession of weather during the summer months in the Corn Belt area of the United States. Three problems are considered: (1) Are there significant correlations between precipitation and temperature factors of the same month? (2) Does the precipitation or the temperature of one month correlate well with either factor for a later month? (3) Are these correlations the same throughout the Corn Belt, or are there significant areal differences within the region?

Data from 30 to 45 Corn Belt weather stations, covering a period of approximately 20 years, have been used in computing simple correlation coefficients. Monthly data for precipitation and temperature for the months of May through August were studied. The temperature data used are the number of degrees above 90° F. for each day, totaled for the month, for each station (here called the accumulated degrees above 90° F.). All data have been used without removing trends.[2]

[1] Presented at the meeting of the American Meteorological Society, St. Louis, Mo., December 1935.

[2] It is a well known fact that if secular trends are present in correlated data, spurious correlations may result merely from the fact that paired values deviate from their respective means partly because of their positions in the time series. Small trends are present in most of the climatological data used. Investigation showed, however, that the coefficients obtained when the trends were removed differed not more than 0.05, mostly only 0.02 or 0.01, from those based on the same data without removing trends. Such differences are not significant in the present problem.